temperature, the resulting spectrum under the supposition that each element is really an element, would never be simpler than the combined spectra of the various elements.

On the other hand, if the elements were really compounds of some one primordial atom, we might expect that a very high temperature would split up their atomic structure, and simplify their spectra, so that at an enormously high temperature a mixture of all the elements might nevertheless give us a very simple spectrum. We might likewise expect that different elements might split up into common constituents, so that at a very high temperature the spectra of these elements would have certain lines in common.

It is in the larger masses of the Universe, the sun and stars that we must look to find a mixture of all kinds of matter at very high temperatures, and when we have a brilliant bluish-white star containing a large proportion of the more refrangible rays we have every reason for supposing this star to be at a very high temperature. Now such stars exhibit an extreme paucity in the black lines which appear in their spectra, in which there is hardly anything else than certain prominent lines seen in the spectra of hydrogen, calcium, magnesium, and sodium. Lockyer, who has devoted great attention to this subject, argues therefore as follows. If it be true that as a rule the atmospheres of the whiter and presumably hotter stars contain fewer elements and those of the smallest atomic weight and that as stars diminish in whiteness their atmospheres rise in complexity of structure this undoubtedly tells in favour of the power of high temperature to split up the so-called elements. He has quite recently carried this reasoning into another field. The Fraunhofer lines give us the integration of the absorptions of all the strata of the solar atmosphere. Now spot phenomena occur in a restricted stratum of this atmosphere, and this stratum is low and therefore hotter than the overlying portions. We can tell the spectral lines special to a spot by their widening, and the number of lines widened is small in comparison with the Fraunhofer lines. Here again we have simplicity brought about by high temperature in the low levels in the sun as in the stars hotter than the sun.

Let us now ask whether the spectra of the various elements have or have not certain lines in common. It used to be imagined that they had not.

When, however, they have been examined under great dispersive power there has been found reason to qualify this assertion. There are certain lines in the spectra of each element which appear long and thick, their predominant notes as it were, and it has been found that while such a line for instance is exceedingly prominent in some one element other elements appear to possess it, only not nearly so prominently. Lockyer's argument from this was that, on the assumption that the elements are truly elementary, the line in the other elements was caused by traces of impurity. He has, however, recently had reason to believe that there are coincidences between the spectra of the various elements not of this nature. There are coincidences of lines which are not the prominent lines of any one spectrum and they give no signs of that variability of brightness that might be expected to characterise lines due to impurities. These lines he has called basic lines. As may be readily imagined in a branch of knowledge which is so new we shall have long to wait for facts. Hence we cannot test this conclusion by referring to the spectra of stars. But Lockyer has already shown that we can test it by means of the spectra of sun-spots, and here the facts are certainly in support of it. The basic lines are more prominent in the spectra of spots than in the spectrum of the sun generally, and further they are more prominent at epochs of sun-spot maximum than during times of minimum.

But we must have a clear conception of what we mean when we suppose that the so-called elements are split up at a very high temperature.

If we apply a very powerful source of electricity we obtain certain peculiar lines from the vapour of calcium.

Now if we could (like the Demon of Maxwell) catch hold of and segregate—put into a box as it were all these minute entities that give us this suspicious line at a high temperature, and further if we could keep their high temperature up I think it is probable that we might obtain something which is not calcium, or at any rate, something simpler than the molecule of calcium as this appears at lower temperatures. But we are not yet able, and perhaps we may never be able, at an ordinary temperature to present the chemist with some other substance derived from calcium which is not calcium.

To conclude there seems little doubt that spectrum analysis will, as it advances, throw great light on the ultimate constitution of matter and it therefore justifies the remarks which I made at the commencement of this lecture.

THE SWEDISH NORTH-EAST PASSAGE EXPEDITION

DESPATCHES have been received by Mr. Oscar Dickson, of Gothenburg, from Prof. Nordenskjöld, giving an account of the wintering of the *Vega*, down to April 1; letters from Lieut. Palander and other members of the North-East Passage Expedition have also been published, some of them bringing down the narrative to a later date. From these we gather the following particulars:—

The *Vega* was frozen in on September 28, in 67° 7′ N. lat. and 173½° long. W. from Greenwich, at the northernmost extremity of Behring's Straits. The land in the neighbourhood forms an extensive slightly rolling plain, bounded on the south by gently-rising hills, which, farther into the interior, are said by the natives to reach a considerable height. The plain is occupied to a large extent by lagoons separated from the sea by low sandy beaches. When the *Vega* was frozen in, the ground was covered with hoar frost and frozen, but still free of snow, so that it was possible to form some idea of the flora of the region. Close to the beach, compact beds of *Elymus* were intermixed with carpets of *Halianthus peploides*; next there stretched a poor level gravelly plain, only covered with a black lichen, *Gyrophora proboseidea*, and some few flowering plants, amongst which *Armeria sibirica* was the most common. South of this, again, was a tract occupied by lagoons and small lakes, whose shores were covered with luxuriant vegetation, consisting of grasses and *Carices*. On the neighbouring high ground, where the soil, derived from weathered strata of gneiss and dolerite, is richer, the vegetation is marked by greater variety. Here were thickets of willows, extensive carpets of *Empetrum nigrum*, and *Andromeda tetragona*, and large tufts of a species of *Artemisia*. Here were found also the frozen remains of the red whortleberry, the cloudberry, *Taraxacum officinale*, and other plants peculiar to the high north. In an excursion to the interior on October 8, Lieut. Nordquist observed that on the driest parts of the *tundra* the most common plants were *Aira alpina* and *Poa alpina*; on the lower places, *Glyceria*, *pedicularis*, and *Ledum palustre*. *Petasites frigida* and a species of *Salix* occurred everywhere, the latter growing in large compact masses covering spots several hundred square feet in extent, the bushes in some places being 3 to 4 feet high.

In the neighbourhood of the *Vega's* winter quarters there were six small encampments, numbering from three to twenty-five tents each, inhabited by Tchuktches to the number of about 200. With these natives there was much friendly intercourse. They were allowed free access to the deck from which, though covered with a multifarious variety of articles, they did not remove the smallest trifle. They were not, however, altogether to be depended on in the statements they made regarding the articles they offered for sale. Thus, on several occasions what were represented to be hares were found to be dead foxes skinned and with the head and feet cut off, and the natives expressed great astonishment at the instant discovery of the deception. When they had acquired a taste for European food, they bartered drift-wood and the bones of the whale for ship-biscuit, and the quantity distributed partly in this way, partly as gifts, was so considerable as to contribute in no small degree to mitigate the famine that threatened to break out among the natives in mid-winter. None of them were Christian, nor could any of them speak any European language, except one or two who could say a couple of words in English or a word of salutation in Russian. Lieut. Nordquist studied their language with such zeal and success, that in a fortnight he could make himself pretty well understood. He has collected materials for a comprehensive vocabulary.

When the *Vega* was frozen in, the sea next the coast was covered with newly-formed ice, too thin to carry a foot-passenger but thick enough to prevent a boat from making any way. On October 3 the Tchuktches walked on board over the ice. Up to the 10th there were weak places between the vessel and the land, and a blue sky in the east still indicated open water in that direction. On the 13th it was ascertained that a belt of drift ice-fields, compactly frozen together, at least thirty kilometres in breadth, lay between the *Vega* and the open sea. The thickness of the newly-formed ice was measured by Lieut. Bruzewitz, with the following results:—

The Thickness of the Ice

On	December 1	56	centimetres.
,,	January 1	92	,,
,,	February 1...	108	,,
,,	February 15	120	,,
,,	March 1	123	,,
,,	April 1	127	,,
,,	May 1	154	,,
,,	June 1	154	,,
,,	July 1	103	,,

For a distance of about six kilometres from the shore the ice lay all winter nearly undisturbed, but farther out it was in continual motion. So-called polynia, or open places, says Nordenskjold, probably occur here all the year round, and in favourable weather accordingly we could see almost constantly a blue water-sky from true north-west to east. A southerly wind in a few days brought the open water within a few hours' walk of the vessel. It then swarmed with seals, which indicates that it was in connection with a sea always open. The neighbourhood of such an open sea probably accounts for the fact that in the fields of drift-ice that surrounded the vessel there was not a seal-hole to be seen. On January 1 Lieut. Bove reached open water by a four hours' walk. From the fact that from a hummock five metres high he could see no boundary to the open water towards the north-east and north, and from the extent of the water-sky in that direction, he concluded that the breadth of the open water was at least thirty-five kilometres. The depth at the edge of the ice was twelve fathoms, the temperature –2° C. The water ran at a considerable speed right from the coast (from south-south-east), apparently a tidal current. The open water swarmed with seals. No polar bear, no walrus, and no birds were seen.

During the long-continued severe cold in the month of January, in the course of which the temperature several times fell below the freezing-point of mercury, the sea appears to have frozen completely for a great distance from the coast, but by February 7 mild weather again commenced, with variable and southerly winds. The same day a faint water-sky was seen at the horizon. Some kilometres to the east the beach was free of ice, and from the heights on land the seamen observed a high sea in the blue streak of water which bounded the horizon. The open water thus appears to have been very extensive. The statement of the natives that it extended to Behring's Straits was perhaps correct.

The temperature during the wintering was as follows:—

	Minimum. °		Maximum. °		Mean. ° C.
October	– 20·8	...	+ 0·8	...	– 5·21
November ...	– 27·2	...	– 6·3	...	– 16·59
December ...	– 37·1	...	+ 1·2	...	– 22·81
January	– 45·5	...	– 4·1	...	– 25·05
February	– 43·8	...	+ 0·2	...	– 25·08
March	– 39·8	...	– 4·2	...	– 21·65
April	– 38·0	...	– 4·6	...	– 18·93
May	– 26·8	...	+ 1·8	...	– 6·97
June	– 14·3	...	+ 6·8	...	– 0·60

On two occasions the barometer was uncommonly high, viz.,

December 22, 6 A.M. 782·0 (0°) mm.
February 17, 6 A.M. 788·1 (0°) mm.

The lowest atmospheric pressure observed before April 1 was on

December 31, 2 A.M. 728·8 (0°) mm.

The weather during the winter was exceedingly stormy, and the direction of the wind near the surface of the earth was almost constantly between north-west and north north-west. But in a stratum of air at no great height there prevailed, to judge from the motion of the clouds, a similar uninterrupted current from the south-east, which when it occasionally sank to the surface of the earth, brought with it heat and comparatively dry air. This is explained by Behring's Straits forming a gate bounded by high hills between the warm atmospheric area of the Pacific, and the cold area of the Arctic Ocean. The winds must here arrange themselves approximately according to the same laws as the draught in the door-opening between a warm and a cold room. The cold stream of air must go below, and the warm above. The mountain heights which the natives say are to be found in the interior of the Tchuktch Peninsula, besides, contribute to the heat and dryness of the southerly and south-easterly winds. For they give to the winds which pass over their summits the properties of the "fohn." The coldest winds have come from south-west to west, that is, from the Siberian Plain. On the existence of two currents of air which, at a certain height above the surface, contend with one another for the mastery, depends again the speed with which the sky in the neighbourhood of Behring's Straits suddenly becomes cloudy and again completely clear.

Nordenskjold remarks that the fall of snow was not particularly great, but as there was no mild weather of any continuance during the winter, so that the snow was never covered with any continuous crust, a considerable portion of the snow remained so loose that it was carried backwards and forwards by the least puff of wind. With a storm or strong breeze, the snow was carried to higher strata of the air, which was so filled with the fine particles, that it was impossible to distinguish objects at the distance of a few yards. But even when the wind was light and the sky clear, there went on a constant snow-storm a few inches in height along the surface of the ground in the direction of the wind, and so principally from north-west to south-east, carrying an immense mass of water in a frozen state over the north coast of Siberia to more southerly regions, and playing a sufficiently important part in a climatic respect, among others as a carrier of cold to the most northerly forests, to deserve the attention of meteorologists.

The most remarkable observations which the wintering of the *Vega* has yielded appear to relate to the aurora Our voyage happened in one of the years, writes

Nordenskjold, of which it was known beforehand that it would be a minimum aurora year. Just this circumstance has, however, allowed me to study, in a specially suitable region, this natural phenomenon under uncommonly favourable circumstances. For here the luminous arches, which also in Scandinavia generally form the starting-points of the ray-auroras, have shown themselves undimmed by the more splendid forms of the aurora, and one could thus devote one's self to collect observations towards a clearing-up of the right nature of these arches undisturbed by accidental accompaniments. Referring for details to a paper he has sent home for publication in the *Transactions* of the Swedish Academy of Sciences, he goes on to say that the aurora, during the winter 1878-79 never appeared with the splendid bands or draperies of rays so common in Scandinavia, but always in the form of faint luminous arches, which remained unaltered in position hour after hour and day after day. They were *constantly* visible when the sky was not clouded nor their feeble light dimmed by the rays of the sun or the full moon. The conclusions Nordenskjold draws from numerous measurements of the height, extent, and position of these arches are, that our globe, even during a minimum aurora year, is ornamented with a nearly constant corona or circle of light, single, double, or multiple, whose inner edge during the winter of 1878-79, had a height above the surface of the earth of about $\frac{3}{100}$ of the earth's radius, whose centre, the "aurora pole," was situated on the radius of the earth which touches the surface about 81° N. lat. and 80° W. lat. (Greenwich), and which, with a diameter of 0·3 of the earth's radius, extended itself in a plane at right angles to the radius of the earth which touches the centre of the circle. This circle of light stands in the same relation to the ray- and drapery-auroras of Scandinavia as the trade-winds and monsoons in the south to the irregular winds and storms of the north. Its light is never distributed into rays, but resembles that which passes through obscured glass. When the aurora becomes stronger the extent of the circle of light is altered, double or multiple arches are visible, generally lying in the same plane and with a common centre, and rays are thrown out between the different bows. Arches are seldom seen lying irregularly to or crossing one another. The area within which the *common arch* is visible (on the supposition that it can no longer be distinguished when its altitude is only 4° above the horizon) is bounded by two circles drawn upon the earth's surface with the aurora pole as the centre, by radii revolving round it at angles measured on the earth's circumference of 8° and 28°. It touches only to an inconsiderable extent lands inhabited by peoples of European origin (the northernmost part of Sweden, Norway, Finland, Iceland, and Danish Greenland), and even in the middle of this area there is a belt passing over the middle of Greenland, the south of Spitzbergen, and Franz Joseph's Land, where the *common bow* commonly forms only a faint "veil" of light in the zenith. This belt separates the regions where the luminous arches are seen mostly on the southern from those where they are seen mostly on the northern horizon. In the area nearest the aurora pole only the smaller, in the middle of Scandinavia only the larger and less regularly formed coronas are visible. But in the last-mentioned region, as in Southern British America, the aurora-storms and the ray- and drapery-auroras become common. The region where the aurora occurs in its most developed state is to be sought for near the circle which, with the aurora pole as a centre, is drawn on the surface of the earth with a radius at an angle measured at the earth's circumference of about 24°.

The tidal observations, when compared with other series made in the Arctic seas, give important indications regarding the distribution of land and sea in the Polar basin. The greatest range at the *Vega's* winter-quarters was only eighteen centimetres, which shows that the sea north of Behring's Straits forms a marine basin of limited extent, connected with the ocean only by sounds. The variations in the height of the water, produced by winds, were much greater. They amounted nearly to two metres. Still greater irregular changes in the position of land and sea appear to have occurred within the memory of man. For the Tchuktches were at one time afraid that the Swedes would cause inundations along the coast. This appears to show that the sudden changes in the position of the earth which are well known in the volcanic regions farther south had extended so far noth. As most of the Tchuktch villages are situated close to the sea, one of the mighty waves which earthquakes give rise to would completely destroy an immense number of them.

The magnetical observations made during the wintering, in an observatory built of ice and snow, which, being necessarily on land, was at a very inconvenient distance from the vessel, consisted of (1) absolute determinations whenever opportunity offered; (2) observations of the changes in the strength and direction of the magnetic forces made along with necessary absolute determinations every hour between November 27 and April 1; (3) five-minute observations on the 1st and 15th of every month from and including January 15.

With reference to the natural history of the region in which the *Vega* wintered, Prof. Nordenskjöld states that it is very poor in the higher plants and fungi, but lichens are abundant. The number of insects and other invertebrate land animals was very small. Land- and fresh-water mollusca were completely wanting. Of coleoptera only twenty species were found, belonging principally to the families *Carabi* and *Staphylini*, with two *Curculiones* and *Chrysomelæ*, and the other orders appeared to be equally poor, with the exception, perhaps, of the *Diptera* and *Podurida*. On the other hand the sea-bottom, though covered with a stratum of water always about 2° C. below the freezing-point, swarmed with a large number and a great variety of the lower animal types, of which the dredging-boat almost daily made a rich collection in the channel, which opened early in summer in the neighbourhood of the vessel. Prof. Nordenskjöld expected that the same avifauna would be found with little variation in all the Polar lands. Experience has, however, shown that this is by no means the case, the Tchuktch peninsula being quite an exception. Birds here occur in much fewer number, but in a much greater abundance of types than in Novaya Zemlya, Spitzbergen, and Greenland, and the bird-world in its entirety has thus quite a different stamp. The birds common on Greenland, Spitzbergen, Novaya Zemlya, and the coast of North-west Siberia, *Larus glaucus*, *eburneus*, and *tridactylus*, *Harelda glacialis*, *Somateria spectabilis*, *Plectrophanes nivalis*, *Phalaropus fulicarius*, and *Tringa maritima*, the common raven and several other species, are found here. But in addition to these the following uncommon birds are met with:—The American eider, the common eider, *Somateria mollissima*, being absent; a greyish-brown goose with bushy yellowish-white feathers round the neck; a swan-like goose, white with black wing-feathers, a species of *Fuligula* marked in white and green with a fine black-velvet head, the beautifully-marked, uncommon *Larus Rossi;* a little brown snipe with a bill widened spoon-like at the point; several beautiful singers, among them *Sylvia Eversmanni*, which for some days visited the coast in great flocks, probably on their way to breeding-places farther north, or waiting till the bushes in the interior should be free of snow. A portion of the purely Scandinavian species here exhibit some variations in colour-marking and size.

The mammalia are also more numerous than in other places visited by the Swedish expeditions. According to Lieut. Nordquist the most common mammal is the hare. It differs from the common Scandinavian mountain hare by its greater size (its weight often rising to

14 lbs.) and by the nasal bone not diminishing so rapidly in size. The mountain fox (*Vulpes lagopus*, L.) is very common. The common fox (*Vulpes vulgaris*, Gray) appears also to be common. A red fox, shot in October, differs considerably from the common, and approaches the mountain fox in several particulars. The fox's food during winter appears to consist of hares, ptarmigans, and lemmings. Of lemmings three species were met with, *Myodes obensis* (the most numerous), *M. torquatus*, and *Arvicola obscurus*. The Tchuktches state that a little mouse also occurs, which Nordquist supposes to be a *Sorex*. The two lemmings often showed themselves above the snow during winter, which was not the case with *Arvicola obscurus*. The wolf was seen only twice. The wild reindeer was also uncommon, traces of them having been seen only once. Traces of the land-bear were also seen, and the natives stated that they were not uncommon in summer. The marmot (*Arctomys*) occurs in abundance. An animal described by the natives as living by the banks of streams is supposed to be the common otter. Two weazel-skins were obtained from the natives. It is not certain whether the ermine occurs there. Only two marine mammals have been seen during the winter, the Polar bear and the ringed seal (*Phoca fœtida*). The latter is caught in great numbers, and along with fish and various vegetables forms the main food of the natives. Of land birds there winter in the region only three species, viz., *Strix nyctea*, *Corvus corax*, and *Lagopus subalpina*. The last-mentioned is the most common. On December 14 two large flocks of ptarmigan, one numbering about fifty, were seen about ten miles from the coast. The raven is common at the Tchuktch villages. Its first egg was obtained on May 31. The mountain owl was seen for the first time on March 11, but according to the natives, it is to be met with all winter. In open places on the sea there occur during winter, according to the natives, two swimmers, *Uria Brünnichi* and *Uria grylle*. Besides these there possibly winter on the sea a species of *Mergulus* and one of *Fuligula*, a specimen of the former having been obtained on November 3, and of the latter on March 9.

(*To be continued.*)

GALILEO AND THE APPLICATION OF MATHEMATICS TO PHYSICS[1]

TWO hundred and ninety-eight years ago to-day (November 5, 1581) Galileo Galilei, then a boy between seventeen and eighteen, matriculated as a medical student in the University of Pisa. At that time Medicine was perhaps the least satisfactory of scientific studies, and though his family had influential professional connections, the empirical maxims and the semi-metaphysical reasons by which they were supported never caught the young man's fancy or satisfied his intellect. We first hear of him listening outside the door in which Ricci, the Court mathematician of Florence, who happened to be spending some time at Pisa with the Grand Duke, taught the pages a little Euclid. For a couple of months Galileo neglected his medicine, and greedily absorbed his Euclid through the key-hole till he found some chance opportunity of introducing himself to the Professor, who was delighted with his new pupil. Ricci presented him with a volume of Archimedes, and the great mathematician and physicist of Syracuse became the spiritual father of the young Italian student. In spite of the straitened circumstances of his family, and the chances of fortune that awaited him in a decorous prosecution of his regular medical studies, he deserted them, and attached himself to Ricci.

Watching one day the long swing of a lamp hung from the roof of a church, we are told that he noted the times it took in oscillation after oscillation, and found that though the arc through which it swept died down till it was scarcely visible, the time it took from each farthest right hand point to the succeeding farthest left hand point of its sweep was always the same. He applied the knowledge he had gained at once to the more accurate measurement of the regularity of the pulse beats. The observation of the student, and the immediate practical application of it, was the sure forerunner of the greatness of the man. He knew that Science is Measurement three centuries before Comte laid it down as the definition of mathematics, or Marks had been born to caricature the maxim in his diploma picture.

At that time the Peripatetic philosophy was dominant over Europe, and tyrannized in Italy. The followers of Aristotle naturally travestied the errors of their master. In his own time Aristotle was a genuine observer of nature, and, as Galileo afterwards said of him, he would have been the last to dispute a fact because it contradicted his preconceived opinions. His followers, who were not observers, had constituted a universe on high *a priori* principles. They taught that there were two great classes of things perishable and terrestrial, one heavy, tending by an irresistible law of their essential nature to the mathematical centre of the universe, the other light, and tending irresistibly away from it. Things imperishable and extra-terrestrial moved by a like necessity in everlasting circles round the centre of all things. A body of 2 lbs. weight, having more tendency to the centre than a body of 1 lb., must fall faster, and acquire a greater velocity in an equal time. With *a priori* principles like these observation was superfluous. Galileo questioned them and put them to the *examen rigorosum* of experiment. The explanation of the isochronism of the larger or smaller swings of the pendulum lay in the fact that though when the moving lamp started from a higher point it had further to fall—it began to fall more nearly perpendicularly and faster, and it swept through its larger arc with a greater velocity at every point. When he took two such pendulums of equal length, to the end of one of which a lamp weighing 1 lb. was fastened, and to the end of the other a weight of 2 lbs., Galileo found that their times of oscillation were the same.

The Peripatetic dictum of the greater gravity of heavier bodies was in contradiction with this simple fact. Galileo took the two weights to the top of the hanging tower of Pisa, and let them fall. They fell at the same or practically the same instant. Though the simultaneous thud of these two weights on the ground was the death-blow of the Peripatetic assumption, it was not enough to convince teachers who had grown grey in teaching it. But a moment's thought now will serve to show us not merely that it is so, but why it must be so. Instead of the mass of 2 lbs., imagine for a moment that the 2 lbs are made up of two single pound weights, each identical in shape and material with the other mass of 1 lb., and that all three drop together. All three will come to the ground together. If the two pound weights are made to adhere to each other by ever so thin a film of glycerine, there will be no strain on the film, and they will not separate If an imaginary section is cut through a single mass of two pounds there will equally be no strain or shearing force along that section. The tendency of the two single lbs. downwards is twice as great as that of the 1 lb., but it has to move two masses instead of one. Ten runners who keep abreast of each other do ten times the work of an eleventh runner on the other side of the course. Man for man, each does the same work, and each man's work has the same effect in producing the racing speed of each. An imaginary or real thread might tie the ten together, but there would be no strain on the thread, which would not snap, if their rates of running were the same.

Galileo often returned to the pendulum, and completely

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[1] An Introductory Lecture, by William Jack, M.A., LL.D., F.R.S.E., Professor of Mathematics in the University of Glasgow, formerly Fellow of St. Peter's College, Cambridge.